Effects of Increased Tramp Element Content in Cast Inconel 718

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PURDUE MATERIALS ENGINEERING

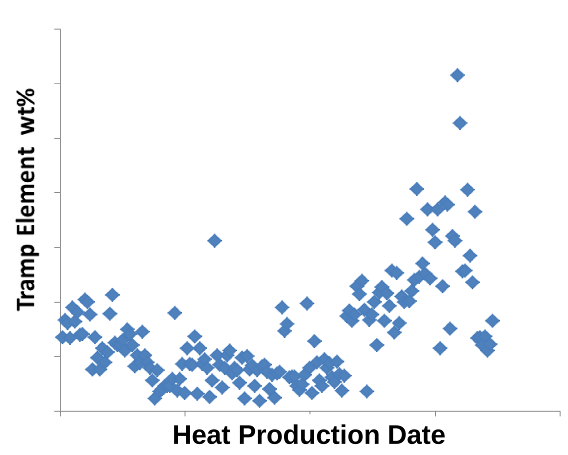
Alcoa Howmet has observed unintentional increases in tramp elements (Cu, Mn, P, Si, and V) in their IN 718 castings. The tramp elements, typically ~ 0.1 wt%, are introduced from scrap or contamination during the production process. The individual effects of Cu, Mn, and Si were studied at two concentration levels each compared to a baseline IN 718. Mn had no significant effect on microstructure or mechanical properties. Cu produced a fine equiaxed macrostructure that resulted in a change in mechanical properties. Si decreased stress-rupture life and increased creep elongation.

This work was sponsored by
Alcoa-Howmet
La Porte, IN

Alcoa Power and Propulsion

Project Background

IN 718 is the highest tonnage superalloy worldwide. To reduce cost Alcoa Howmet increased the use of recycled materials in their alloy production, including outsourced or commercially purchased scrap. As a result, an upward trend in tramp element content was observed.



Because tramp elements can be detrimental to performance, this project aims to study how such increases affect microstructure, mechanical properties, castability, and weldability of the alloy. The focus of this study was on the elements Cu, Mn, and Si.

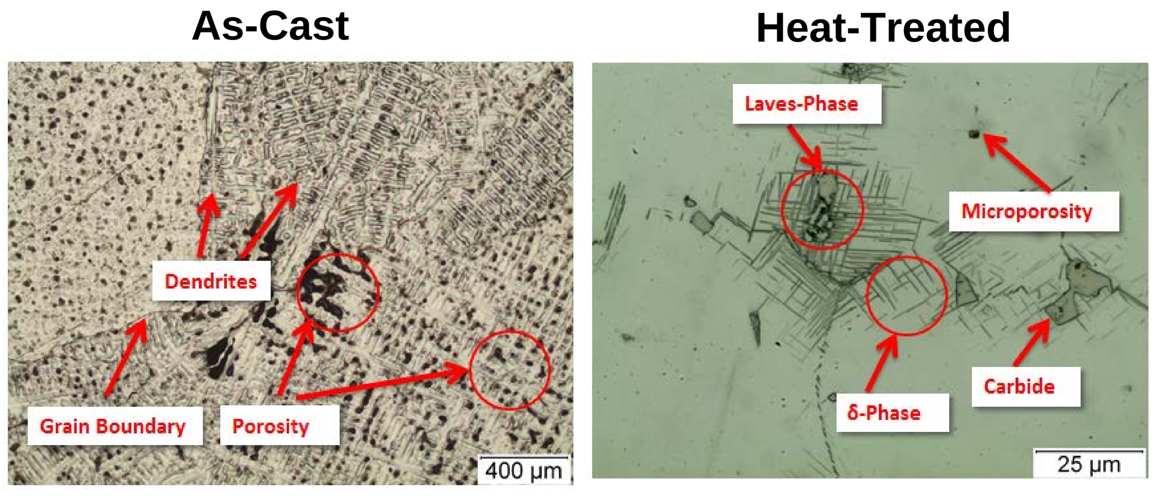
IN 718: Nominal Composition (wt%) [AMS 5383]

Primary Elements	Ni	Cr	Fe	Nb	Mo	Ti + Al	Ti	Co	C	B
	55.0	21.0	17.0	5.50	3.30	1.75	1.15	1.0	0.06	0.006

Tramp Elements (Max limit)	Cu	Mn	S	Si	P
	0.30	0.35	0.015	0.35	0.015

Cast IN 718 Microstructure

IN 718 solidifies dendritically and contains fine interdendritic micropores and carbides. Both clustered and scattered-uniform porosity are typical, and some areas contain secondary phases, Laves [$(Ni,Fe,Cr)_2(Nb,Mo,Ti)$] and δ [Ni_3Nb]. Heat treatment further develops this microstructure.



Experimental Plans

Composition Selection

A baseline master heat was created, then six variations were made by adjusting tramp element content. These compositions were selected based on the specification limits and historical Alcoa-Howmet data. The upper levels were at the maximum allowable limits.

Primary Elements	Ni	Cr	Fe	Nb	Mo	Ti + Al	Ti	Co	C	B
	52.0	18.8	19.5	4.9	3.0	1.4	0.19	0.15	0.06	0.005

Tramp Elements	Cu	Mn	S	Si	P	Six Composition variants					
						Cu		Mn		Si	
	0.02	0.02	0.001	0.05	0.006	0.17	0.30	0.20	0.35	0.22	0.35

Test Plan

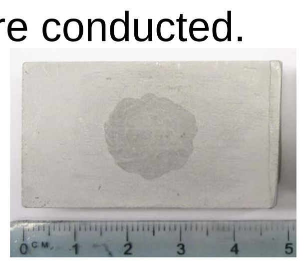
One mold of each alloy was cast producing 12 test bars and 2 chem. blocks. Seven of the bars were subjected to standard heat treatment: homogenized 1-2 h at 2000 °F, solution heat treated 1 h at 1800 °F, and aged 8 h at 1325 °F and 8 h at 1150 °F.

7 heat treated cast-to-size test bars

Castability: Density was measured by immersion. Porosity and carbide vol. % were measured by systematic point count stereological technique and supported by image analysis software ImageJ.

Mechanical Properties: Duplicate tensile tests at room temperature and 1200 °F (649 °C) and triplicate stress-rupture tests at 65 ksi (448 MPa)/1300 °F (704 °C) were conducted.

Weldability: Welds were made on chemistry blocks and microstructural differences at the weld interface were evaluated.



Weldability Sample

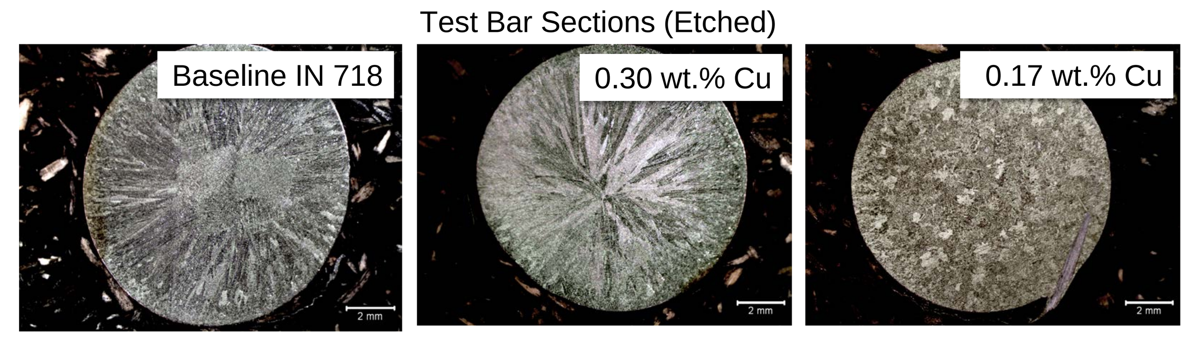
Results and Discussion

Castability

As-Cast Macrostructure

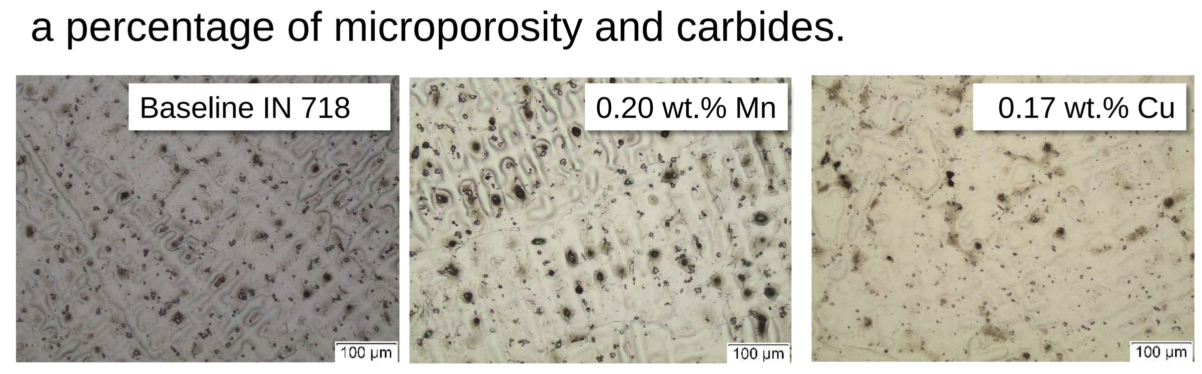
The baseline displayed a typical macrostructural pattern of radial columnar grains with some equiaxed grains toward the center. Heats with altered compositions were consistent with baseline IN 718 macrostructure, except for 0.17 wt% Cu, which had a fully equiaxed grain structure.

Test Bar Sections (Etched)



As-cast Microstructure

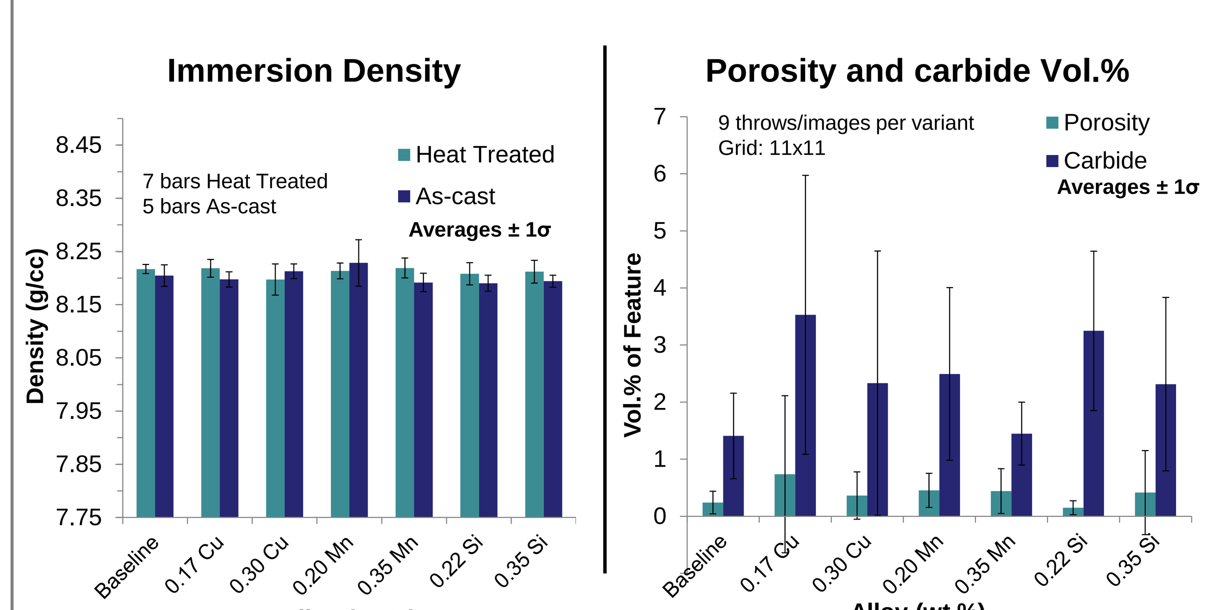
All heats presented similar intragranular microstructures with a percentage of microporosity and carbides.



As-cast etched microstructures showing consistent dendritic structure

Quantitative Metallography

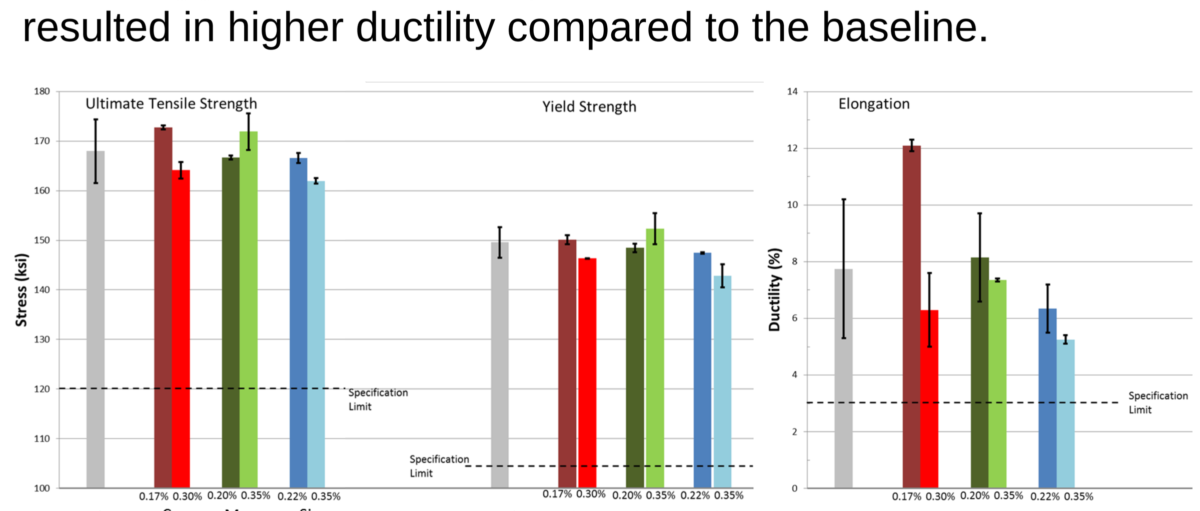
Immersion density measurements did not show statistically significant differences between compositions. The porosity for all the heats was less than 1 vol.%. The fraction of carbides ranged from 1.5 to 3.5 vol.%. Carbide and porosity fractions were not statistically different from the baseline.



Mechanical Properties

Room Temperature Tensile

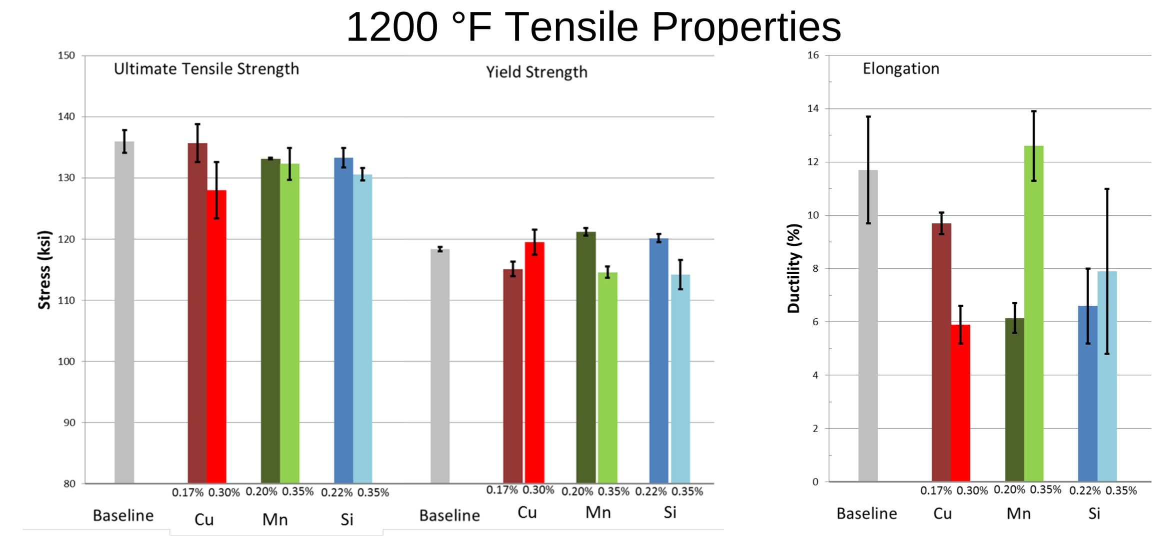
All parameters exceeded the specification minimum requirements. No statistical difference was found between any of the six variant compositions and the baseline. Part of this stemmed from small sample sizes. 0.17 wt% Cu had higher ductility, UTS, and YS when compared to 0.30 wt% Cu. The data suggests that the equiaxed structure of 0.17 wt% Cu resulted in higher ductility compared to the baseline.



1200 °F Tensile:

In ultimate tensile strength and yield strength, no composition showed a statistical difference from the baseline. Some decreases from the baseline are observable for elongation in 0.30 wt% Cu, 0.20 wt% Mn, and 0.22 wt% Si, but these are not statistically significant. (Top of next column)

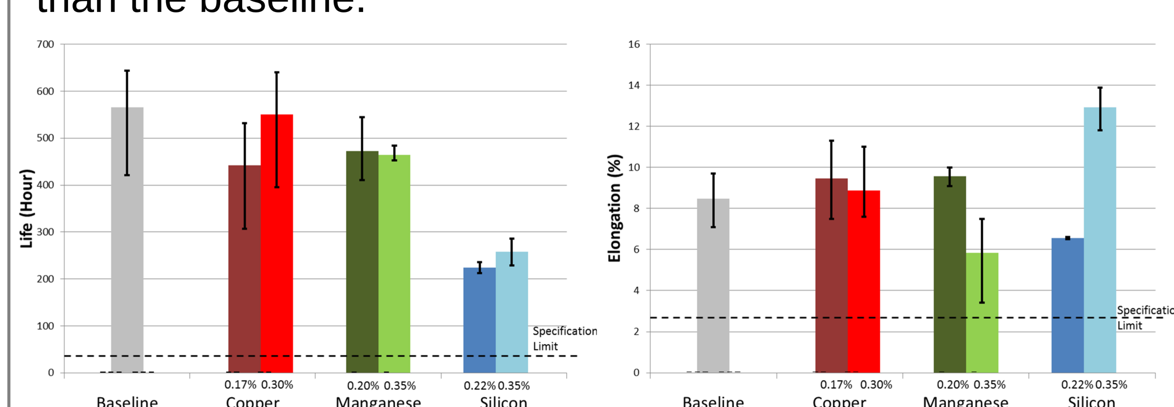
1200 °F Tensile Properties



Note: There is no specification for 1200 °F tensile testing.

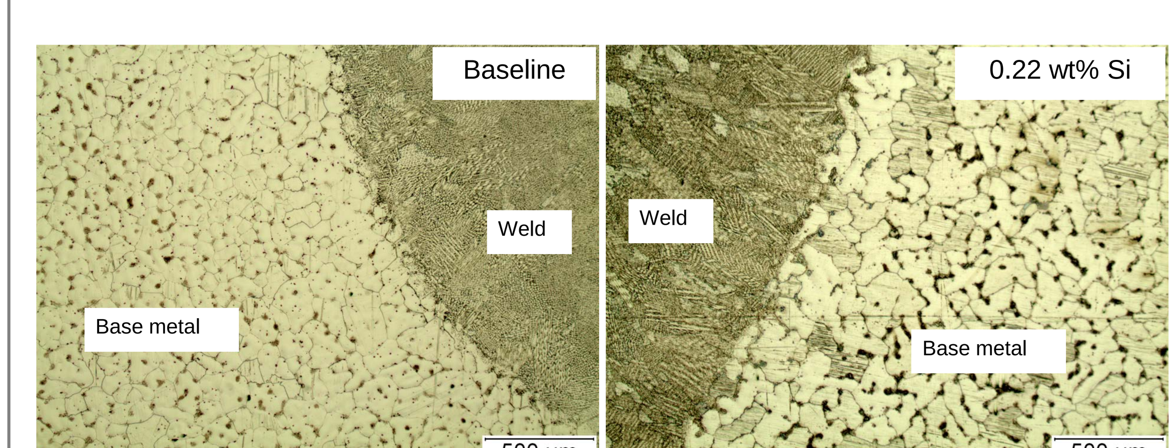
Stress-Rupture 1300 °F, 65 ksi (704 °C, 448 MPa)

Stress-rupture life of 0.22 wt% Si was statistically lower than the baseline, while 0.35 wt% Si was not, although sample size was small. 0.17 wt% Cu showed slightly lower life, likely due to fine equiaxed grain structure. Elongation of 0.22 wt% Si was lower than the baseline, while 0.35 wt% Si was higher than the baseline.



Weldability

All alloys showed characteristic heat affected zones. No indications of incipient melting were observed. These would likely have appeared as spherical pores surrounded by secondary phases within the heat affected zone adjacent to the weld material. No evidence of microcracking was observed in any of the welds. These observations suggest no effect on the weldability of any of the compositions tested.



Conclusions

- Cu, Mn, and Si additions up to composition limits do not yield properties below the specification limit.
- Individual effects up to the specification limit are acceptable, however interactive effects are unknown.
- An equiaxed solidification pattern was shown by 0.17 wt% Cu, corresponding to significantly increased RT tensile ductility but slightly decreased stress-rupture life.
- No statistically significant differences in density, porosity, or carbide content were observed.
- If either Cu or Mn concentration increases up to the specification limit, the properties should not be significantly affected.
- If Si is present in concentrations at the specification limit, stress-rupture life may be reduced ~50% with increased elongation.
- No individual element (Cu, Mn, Si) impacted weldability.

Recommendations

It is recommended to conduct a controlled interactional study by iterating the maximum compositional values of Cu, Mn, and Si. For consistency, the same experimental design (castability study, mechanical property testing, and weldability study) should be utilized.